The Measurement of Long Lived Alpha-Decays

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Abstract

Alpha-decay has historically given insight into the inner workings of the nucleus as the decay rate is strongly affected by nuclear structure. Very long lived alpha-decaying isotopes (about $T_{1/2}$ = 1-100 Gyr) can be used as a powerful tool to date the formation of astronomical objects in the Solar System due to their extremely long half-lives. This technique is however very vulnerable to the accuracy of the half-life. This means that improved half-life measurements are important though they pose a significant technical obstacle.

Cosmo(Geo)-Chronometer

If a material contains isotopes that undergo radioactive decay with a half-life that is comparable to its age, the isotopic abundances of these isotopes are strongly correlated with the age of the material. The half-life of the decaying isotope can then be used to infer an age.
A good example of this is the alpha-decay of ^{147}Sm into ^{143}Nd. This process has a half-life of 1.060(11) Gyr and has many dating aplications.

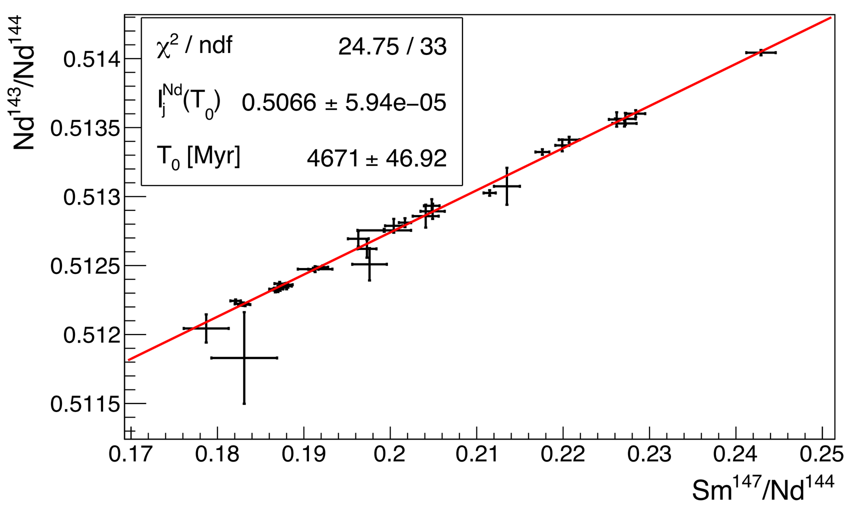
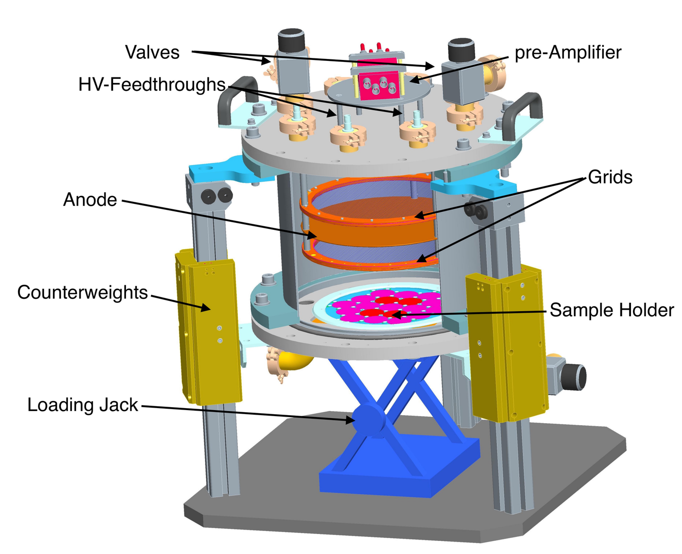


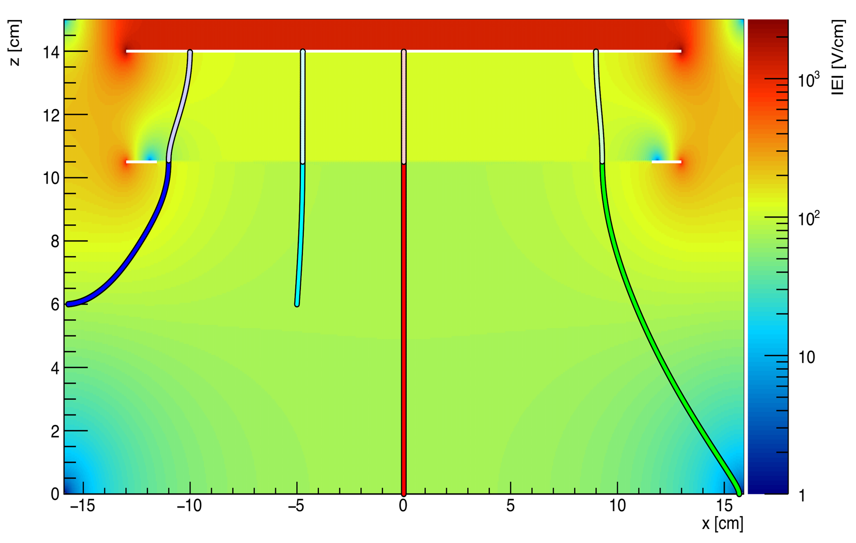
Fig. 1: Isochron plot for chondritic phosphates and chondrules. Data taken from Planetary Science Letters **223**, 267-282 (2004).

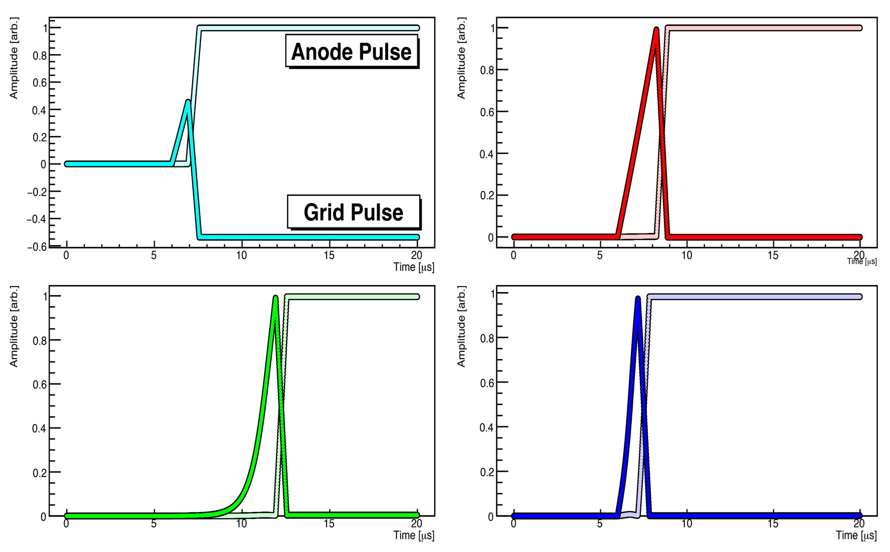
Detector Design

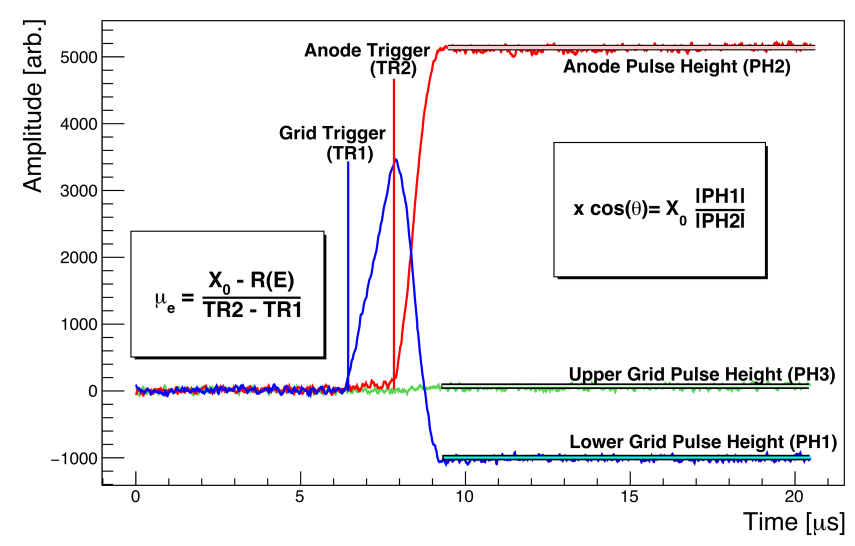


To measure the half-lives of such long lived isotopes special care needs to be taken with background and signal efficiency. To overcome these obstacles the design of the twin Frisch-Grid ionisation chamber was chosen (1). The Frisch-Grid design utilises a grid to shield the anode from the ions which means that the signal only depends on the ionised electrons. The electron signal is faster and has no angular dependance which results in excellent energy resolution with a high detector efficiency. This allows for the measurement of decay rates in the region of a few counts per day (c.p.d).

Pulse Shape Analysis

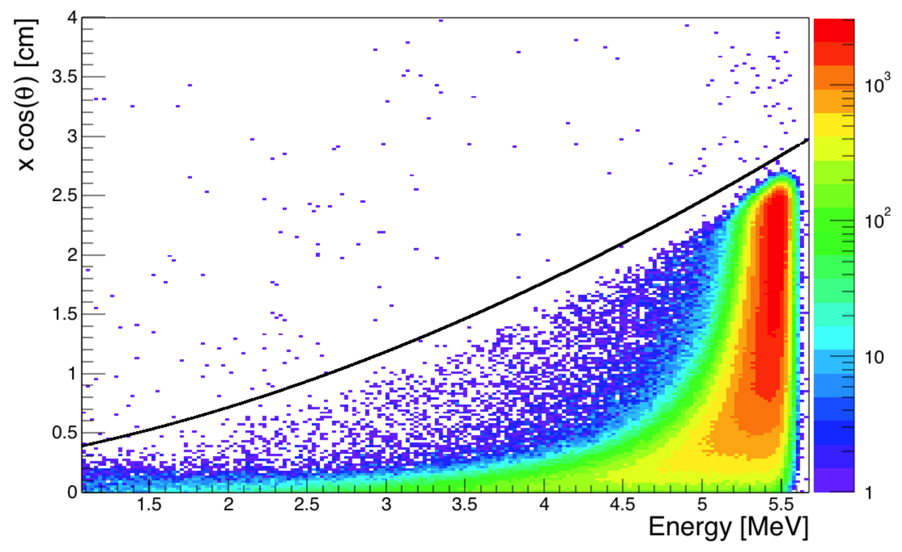


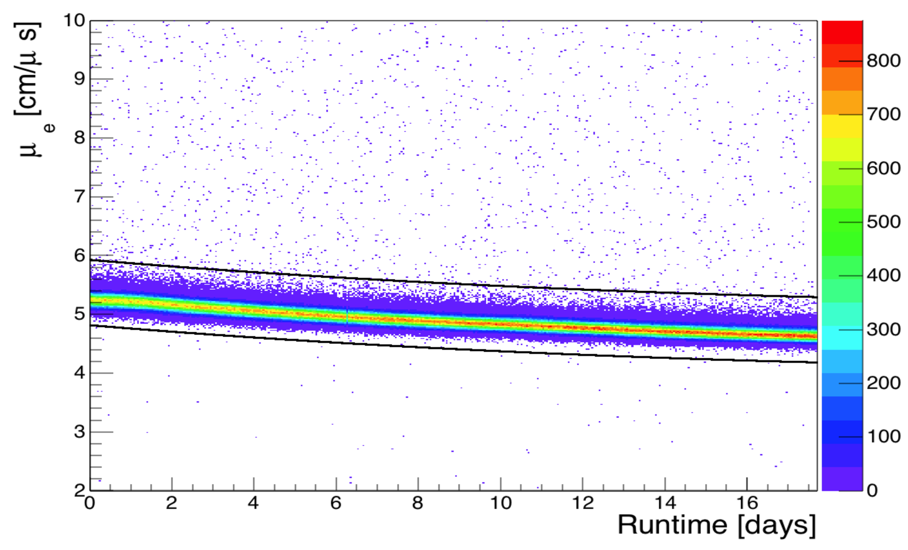




Pulse shape analysis is used to obtain position information on each event, allowing for improved signal to background discrimination. The pulse shapes can be calculated using the Shockley-Ramo theorem. A GEANT4 simulation is used to simulate the ionisation caused by the alpha particles in the chamber.

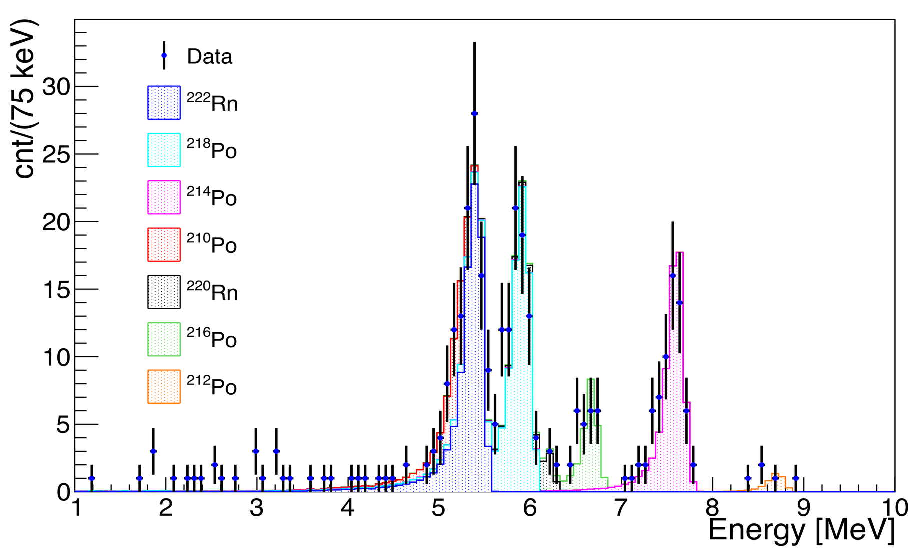
Analysis

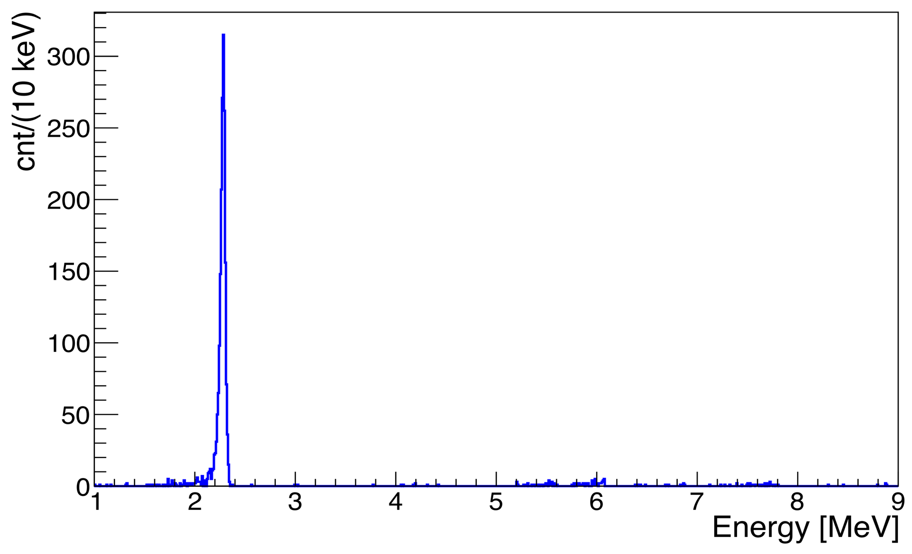




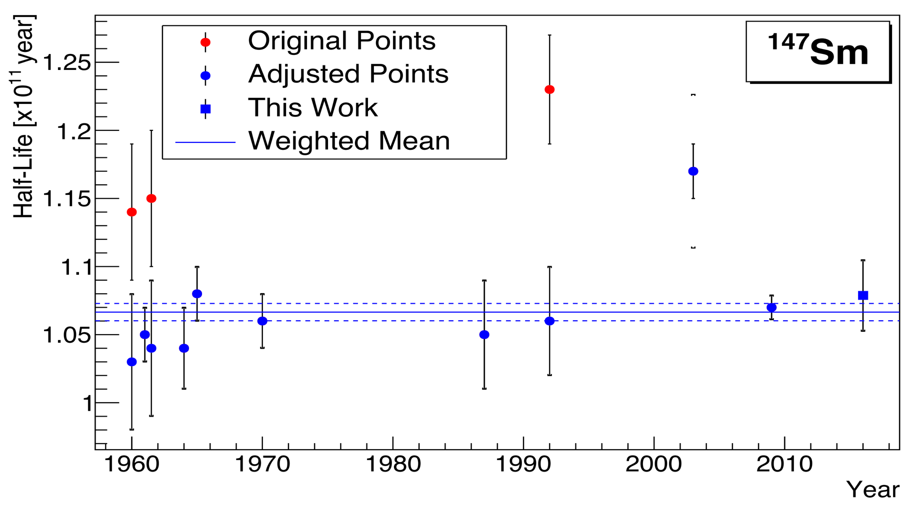
Each pulse shape is recorded into a ROOT file for later offline analysis. The parameters that are determined from the pulse shape are the velocity of the signal carriers (μ_e) and the vertical projection of the charge cloud ($x \cdot \cos(\theta)$). Cuts have been developed to enhance the signal to background efficiency. The total efficiency is 98.6(22)%.

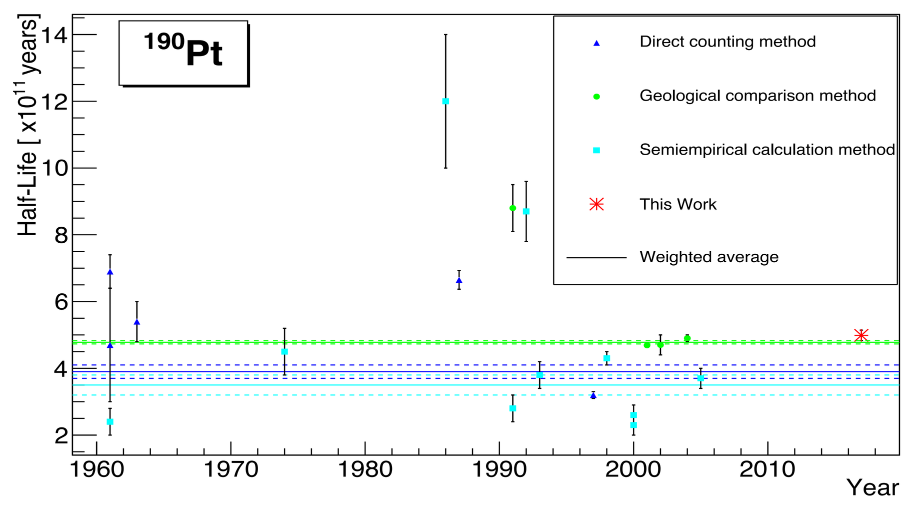
Results





A background rate of 10.9(6) c.p.d was measured (1) over the period of 30.8 days. Most of the contamination comes from the decay of ^{220}Rn which is only concentrated around the 5 MeV energy region. For the alpha energy of ^{147}Sm at 2.248(1) MeV the background is much lower.





The recently measured half-life of ^{147}Sm of 107.9(26) Gyr (2) compares well to the accepted value of 106.0(11) Gyr. The results are combined to determine a new weighted average of 106.7(6) Gyr.
The ^{147}Sm results encouraged the measurement of other long lived alpha-decays such as ^{190}Pt. The resulting ^{190}Pt half-life of 497(16) Gyr (3) is the first measured half-life that agrees with the weighted mean obtained by the geological comparison method of 478(5) Gyr. Further investigations into long-lived alpha-decaying isotopes are planned for the future.

Summary

The above work shows the successful construction of a low-radiation chamber specifically designed to measure long living alpha-decays. The sensitivity to these decays has been enhanced with the use of data analysis cuts based on the physics parameters of the chamber. The chamber has been used to measure half-lives in the region of 100 Gyr.

(1) H. Wilsenach et al. In: *NIM A* 814 (2016), pp. 12 –18.
(2) H. Wilsenach et al. In: *Phys. Rev. C* 95 (3 2017), p. 034618.
(3) H. Wilsenach et al. In: *Phy. Let. B* 768 (2017), pp. 317 –320.

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PhD project is supported by the
DFG graduate school GRK 1504
"Mass, Spectrum, Symmetry"

GRADUIERTENKOLLEG Masse-Spektrum-Symmetrie